

Progress in Design and Construction of the Optical Communications Telescope Laboratory (OCTL)

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ABSTRACT

JPL is constructing an Optical Communications Telescope Laboratory (OCTL) at its Table Mountain Facility complex in the San Bernadino Mountains of Southern California. The OCTL will house a 1-m class telescope and serve as an R&D ground station supporting future optical communications demonstrations with Earth-orbiting satellites and deep space probes. It will also support research in adaptive optics, optical receiver technologies, and help in developing spacecraft acquisition and tracking strategies from future optical ground stations. The OCTL building was completed in November 1999, and Brashear-LP of Pittsburgh, PA has been selected to build the telescope. First light is expected in July 2001.

Keywords: Free space optical communications, lasercom, telescopes, ground stations, adaptive optics, astrometry, Table Mountain Facility

1.0 INTRODUCTION

Optical communications is recognized as a viable option to meeting the need for high speed communications in small, low-power consumption, and low mass packages from Earth-orbiting satellites and deep-space probes^{1,2}. Q-switched solid-state lasers with PPM modulation schemes can support data rates up to 100 kbps from a 30-cm transmitter at Jupiter into 10-m Earth receiver.³ Recent developments in high power fiber amplifiers at the 1550-nm wavelength band have opened the door to the implementation of dense wavelength division multiplexing strategies in terrestrial free-space optical communications that will lead to supporting multi-gigabits per second space-to-ground links⁴.

JPL is building a 1-m class optical communications telescope laboratory (OCTL)⁵ at its Table Mountain Facility near Wrightwood, CA to support its optical communications research program. The OCTL will support future optical communications demonstrations with Earth orbiting satellites and perform research into key areas that affect the optical link performance. It will support research in low-noise receivers, adaptive optics for uplink beam propagation and multi-beam propagation options. Field-of-view reduction to mitigate the sky background effects that impact receiver signal-to-noise ratio (SNR), and strategies to acquire and track satellites for daytime and nighttime communications will also be explored.

In this paper, we describe the progress to date in the design and construction of the OCTL. In section 2, we discuss the performance specifications of the telescope, the pier and the dome that were conveyed by JPL to Contraves-LP (formerly Contraves/Brashear), and give estimated dates for reviews and for first light. In section 3 we describe the design philosophy and the construction of the OCTL building.

2.0 TELESCOPE, PIER, AND DOME

The telescope contract was awarded to Contraves-LP, Pittsburgh, PA on January 27, 2000. It is a fixed price contract, and calls for delivery and integration of the telescope, the pier and the dome at TMF in eighteen months. The preliminary design

review is to be completed by the end of April 2000 and the critical design review by August 2000. Key performance requirements to the telescope are:

- Low optical throughput losses
- Coude path and support high power laser transmission ($>10 \text{ MW/cm}^2$ peak optical power densities and 100 Watts average power).
- Telescope optical path must be vibration and thermally isolated from laser lab
- Must operate as close as 30 degrees to Sun
- Must track spacecraft from shuttle to deep space ranges. See tracking requirements given in Table 2.1

Table 2.1: Required tracking performance of OCTL telescope

Elevation Velocity ($d\Theta/dt$) deg/sec	RMS LOS jitter in Bandwidth of 0.1-20 Hz	RMS LOS jitter in Bandwidth of > 20 Hz
Stationary to Planetary $0/0=d\Theta/dt<0.007$	Required $< 10\mu\text{rad}$ Desired $< 2\mu\text{rad}$	$< 1\mu\text{rad}$
MEO to HEO $0.0071<d\Theta/dt<0.54$	$< 10\mu\text{rad}$	$< 1\mu\text{rad}$
LEO $0.5<d\Theta/dt<2.0$	$< 10\mu\text{rad}$	$< 1\mu\text{rad}$

The telescope blind-pointing 3σ error after an all-sky mount calibration is specified to be less than $15\mu\text{rad}$ over the temperature range -10°C to $+40^\circ\text{C}$. The low line-of-sight jitter specified in Table 2.1 will allow the uplink laser beam divergence to be adjusted to maintain the required uplink beacon margin as the track takes the propagating through thin cirrus clouds. This capability will allow a comparison between multi-beam and atmosphere-corrected uplink beams approaches being considered for beacons to deep space probes.

To meet the performance requirements, the telescope will have:

- 1-m clear aperture primary mirror
- Mirrors M2- M7 coated with protected silver Denton FSS -99 or a coating of corresponding reflectivity and durability
- An optical throughput
 - $> 67\%$, $500\text{-nm} < \lambda < 600\text{-nm}$
 - $> 72\%$, $\lambda > 600\text{-nm}$
- A prescription that supports encircled energy requirements of
 - $> 66\%$ in $1.54 \mu\text{rad}$ (Airy disk)
 - $> 80\%$ in $2.81 \mu\text{rad}$ (Airy disk & first ring)
- A plate scale $\Rightarrow 92 \mu\text{rad/mm}$
- Less than 10% degradation in performance over expected -10°C to $+40^\circ\text{C}$ operating temperature range at TMF
- Baffled optical path for daytime operation at $\sim 30^\circ$ from the sun
- A 0.4° wide-field acquisition telescope boresighted with the 1-m telescope to within $50 \mu\text{rad}$.
- Ability to track targets with less than 2 arc sec line-of-sight RMS jitter at frequencies below 20 Hz.
- Telescope control software that supports operation with TDRS, NORAD, and GPS predicts.

The telescope pier is a 2.1 -m diameter tubular structure with a 0.6 X 1.5-m high ship's door to provide access to mirror M7. The current design calls for a thermal isolation window (BK-7 or fused silica) installed in the pier between the M6 and M7 mirrors at the approximate height of the dome floor. This approach prevents convection currents from transferring heat between the laser lab and the dome, and thus mitigates the effects of dome "seeing". The telescope and dome are thus maintained at the ambient external temperature, unaffected by the heat generated in the laser lab. This heat is exhausted down wind from the building to reduce its effects on seeing at the telescope. A constant flow of forced air blown across both the upper and lower surfaces of the window serves both to stabilize the thermal gradients across the window and to prevent dew formation on the window.

The dome is required to support the tracking specifications of the telescope. The current design calls for an insulated dual aluminum skin structure with a 2.9-m inside radius. Two sliding doors with rapid opening and closing ability provide a 1.52-m aperture to maintain clear line of sight for both the main and the acquisition telescopes. The dome is to be designed to operate in 30 mph winds, survive 130 mph winds and to support snow loads of 75 lbs/sq.ft.

3.0 BUILDING

Ground breaking for the building was May 24, 1999. Construction was completed in November 1999 with the final inspection and walk through held on November 22. A cross-section of the OCTL building accenting the telescope, the dome enclosure, the laser lab area and foundation are shown in Figure 3.1. The telescope and pier are anchored to a concrete slab that forms the laser lab. This slab is vibration-isolated from the remainder of the building, and is in turn anchored 0.45-m deep into the bedrock by five cast-in-drilled-hole concrete piers⁶. The bedrock below the OCTL building is located approximately 3-m below the surface colluvium soil.

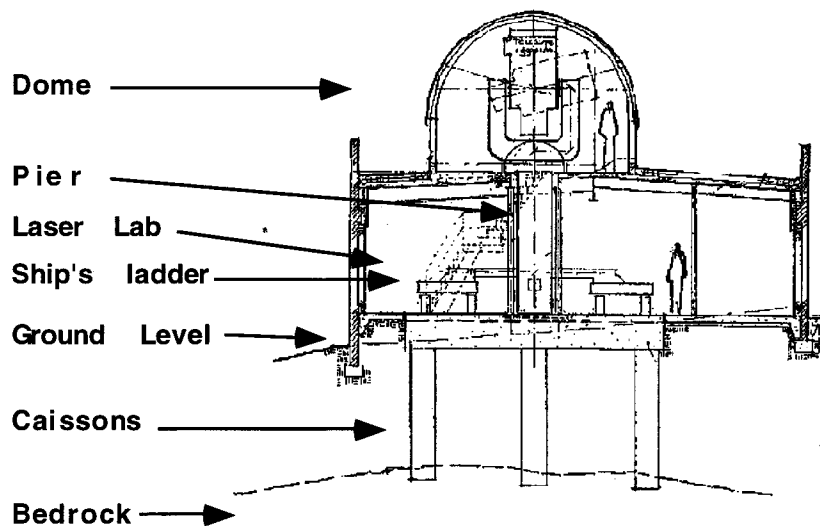


Figure 3.1: Architect's schematic of OCTL building section showing the caissons that anchor the laser lab 8 meters into the bedrock.

Key building requirements were as follows:

- Provide sound structural support for telescope and dome
- Be acoustically isolated from telescope
- Support multiple experiments at coude including high power laser transmission
- Have low thermal signature

The floor plan of the 200 sq.-m building is shown in Figure 3.2. The air-conditioning and electrical utilities rooms are vibration-isolated from the remainder of the building and heat generated in the laboratory is vented to through an exhaust located 50-m downwind from the building. Computers for the telescope control data recovery and analysis are located in the telescope control room that also serves as a work area for the staff. Access to the telescope and dome is via a ship's ladder from the laser lab.

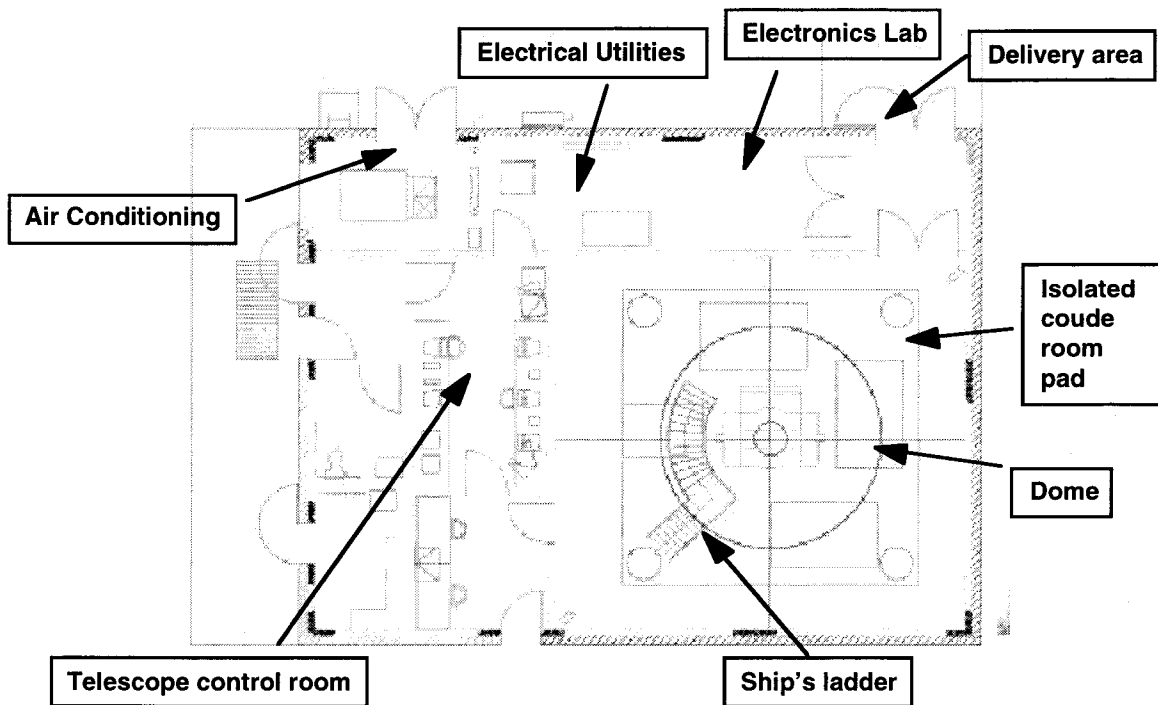


Figure 3.2: Shows the OCTL building floor plan and the layout of the laser laboratory. The air conditioning and electrical utilities rooms are on separate and vibration-isolated concrete slabs from the main building. The outline of the dome and the ship's ladder that provides access from the laser lab to the telescope are also shown in the figure.



Figure 3.3: View of the North face of the completed OCTL building. The exhaust system for venting heat generated in the building downwind from the telescope is shown in the foreground. The temporary dome enclosure is shown above the roof-line.

A picture of the completed OCTL building is shown in Figure 3.3. This view shows the main entrance and the access ladder to the roof. The temporary enclosure erected in place of the telescope dome is seen above the building roof-line. The small shed in the foreground is the downwind exhaust for heat generated in the building.

We chose asphalt for the roadway to reduce the effects of thermal discontinuities material-to-air boundaries near the building that could degrade atmospheric seeing. Studies showed that asphalt tracked the variations in the ambient temperature more closely than did concrete⁷, and that it would therefore impact the seeing changes with diurnal temperature variation less than concrete would. The building roof is made of Cross-Guard Resistite standard white⁶, a material with greater than 80% reflectivity. The low absorption of the roof material reduces the heat re-radiated into the atmosphere and hence the generation of turbulence at roof-level.

4.0 CONCLUSION

NASA/JPL is constructing a 1-m class optical telescope to support its deep-space optical communications program. The telescope building was completed in November 1999, and Brashear-LP is on contract to deliver the telescope by August 2001. The telescope will allow support for NASA's deep-space optical communications research and development work including demonstrations with Earth-orbiting satellites.

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